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North Sumatra's Food Availability Model: Technology Adoption, Farmer Organization Support, and Geographic Variability

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Abstract

This Food availability is a strategic issue affecting economic stability and community welfare, particularly in agrarian regions such as North Sumatra Province. This study aims to analyze factors influencing food availability, including institutional support, geographic variation, and the adoption of agricultural technology. Data were collected through a survey of 100 rice farmers in Percut District, Deli Serdang Regency, using a structured questionnaire. Analysis was conducted using Structural Equation Modeling (SEM) with Smart PLS software to evaluate validity, reliability, and relationships among variables. The results indicate that institutional support and geographic variation significantly affect food availability, while the adoption of modern agricultural technology does not show a significant effect. Institutional support, including training, extension services, and production facilitation, enhances farmers' productivity, whereas physical environmental conditions, such as soil quality, topography, and rainfall, are primary determinants of production success. These findings emphasize the importance of strengthening institutional capacity and regional management as policy priorities, while technology implementation should be adapted to local needs and farmers' capacities. Limitations include a restricted geographic scope and technology variables that do not fully capture modern agricultural complexity. This study provides a conceptual foundation for strategies aimed at enhancing food security and guiding local policy interventions.

Keywords: Agricultural productivity, Food availability, Geographic variation, Institutional support, Technology adoptionagricultural productivity

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1. Introduction

Food security is one of the strategic issues that continues to be a major concern in developing countries because it determines economic stability and community welfare (Pawlak & Kołodziejczak, 2020). The agricultural sector plays an important role as the main source of food (Priefer et al., 2016), especially in countries such as Indonesia, which relies on agriculture as the foundation of its national economy. Food security is also a key factor in driving innovation in science, technology, and labor productivity, as well as creating an economic environment conducive to long-term development. However, Indonesia's food security index still ranked 71st out of 113 countries in 2016, according to The Economist Intelligence Unit (Chammem et al., 2018). On the other hand, global food consumption continues to increase by 18%–21% per year, while production has not been able to keep pace with this increase (Davis, 1989). This condition shows that improving the food supply system is an urgent need and an important basis for discussions on the national potential for maintaining food availability.

The Indonesia has great geographical potential to support national food security, thanks to its rich natural resources and favorable climate conditions for agricultural activities. Modern technology and infrastructure are needed to optimize this potential and maintain food stability. However, challenges arise not only from technical aspects, but also from social, cultural, and regional aspects that reflect the community's ability to adapt to environmental dynamics (Saleh et al., 2020). The development of agricultural productivity is increasingly dependent on technological and scientific innovations that are appropriate to local characteristics(Blanch et al., 2017; Yang et al., 2016) , including the adoption of smart farming, digital agriculture, and modern mechanization, which are increasingly being used in various developing countries . Therefore, the successful dissemination of agricultural technology requires the support of effective extension services that are able to reach a wide range of farmer groups.

Food productivity is ultimately greatly influenced by the quality of agricultural human resources, especially farmers as the main actors in production. Strengthening farmer groups needs to be directed towards the implementation of agribusiness systems that can foster collaboration between farmers and with various stakeholders. The performance of agricultural extension workers is an important factor because they play a direct role in providing technical guidance to

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farmers in the field (Anwarudin et al., 2022; Bahua, 2016; Ferroni & Zhou, 2017; Sabir et al., 2018). The low number of extension workers and their uneven competence contribute to low food production increases. This condition is also exacerbated by farmers' low access to modern agricultural technologies, such as weather monitoring applications, smart irrigation systems, and the use of high-quality seeds (Glendenning et al., 2019; Mansour et al., 2019; Prastyono et al., 2023) Therefore, improving the competence of agricultural workers and the welfare of farmers is an urgent need to strengthen the foundation of national food security.

North Sumatra Province is one of the regions with great potential for agricultural development due to its favorable land conditions, climate, and diversity of commodities produced. Rice production in this region continues to show an upward trend every year (Lubis et al., 2022), and rice contributes the most to the Gross Regional Domestic Product (GRDP), reaching 21.77% (BPS Sumatra Utara, 2014). In addition to rice, several other leading commodities such as coffee, rubber, and palm oil also play a role in strengthening the regional economy and are strategic export commodities. The geographical conditions and potential of these commodities make North Sumatra the right region to study food availability models through a geographical variation approach, farmer organization support, and the adoption of modern agricultural technology. Therefore, this research is important to gain a more comprehensive understanding of the factors that influence food availability in the region.

2. Literature Review and Research Model

2.1 Food Availability and Food Security

Food availability is a strategic issue in developing countries, including Indonesia, which is highly dependent on the agricultural sector as its main source of food (Pawlak & Kołodziejczak, 2020; Priefer et al., 2016). Food security encompasses not only production volume, but also distribution and accessibility, which are directly related to a country's food resilience. Food security is an important factor in creating economic stability, increasing labor productivity, and encouraging technological innovation in the agricultural sector (Chammem et al., 2018). Thus, developing a robust food security system is a strategic priority for every country.

2.2 Population Growth and Food Demand Challenges

Population growth and changing consumption patterns have a direct impact on global food demand. (Davis, 1989) show that global food consumption is increasing by an average of 18%–21% per year, which is often not matched by an increase in production. This phenomenon underscores the need for efficient food production and distribution strategies that are adaptive to changes in demand. In Indonesia, its favorable geography, natural resources, and climate are important assets for ensuring national food security. However, social, cultural, and regional factors also pose challenges to the implementation of food security systems (Saleh et al., 2020).

2.3 Farmer Productivity and Technology Adoption

Agricultural productivity is greatly influenced by the quality of farmers and their ability to adopt technology. Research shows that the application of modern agricultural technology, including mechanization, advanced irrigation systems, and organic fertilization, can significantly increase crop yields (Akyazı, 2023; Blanch et al., 2017; Yang et al., 2016). In addition, the support of farmer organizations and agricultural extension workers plays an important role in facilitating technology transfer and improving farmers' agribusiness management skills (Anwarudin et al., 2022; Ferroni & Zhou, 2017). The combination of technological capabilities, organizational development, and improved welfare can promote sustainable productivity and food security.

2.4 The Role of Geography and the Contribution of North Sumatra Province

North Sumatra has great potential to support national food security through the development of rice commodities. Rice production in North Sumatra shows an upward trend every year and contributes significantly to the Gross Regional Domestic Product (BPS Sumatra Utara, 2014; Lubis et al., 2022). Several agricultural commodities in this region are also export commodities, so food availability management has an impact not only on local food security but also on the national economy. This study emphasizes the importance of understanding the relationship between geographical variation, farmer organization support, and technology adoption in shaping an effective food availability model.

3. Research Method and Materials

This study was conducted from January to July 2023 in Percut District, Deli Serdang Regency, North Sumatra Province. This study used a quantitative approach with a causal model to test the proposed hypothesis. Stratified sampling was applied to select respondents so that the sample could adequately represent the population. The research population consisted of 357 rice farmers in the subdistrict, from which 100 respondents were selected using a structured questionnaire. The questionnaire was designed to provide an overview of the food availability model in North Sumatra, focusing on geographical variations, farmer organization support, and technology adoption (Hair et al., 2021; Henseler et al., 2015).

Data analysis was performed using Structural Equation Modeling (SEM) through the Smart PLS program. SEM is a multivariate statistical technique that combines factor analysis and regression, allowing researchers to test the relationships between latent variables in a conceptual model (Hair et al., 2019; Ringle et al., 2015) . The analysis was conducted in three stages, namely: outer model evaluation, inner model evaluation, and hypothesis testing.

The outer model assesses the relationship between latent variables and their indicators to ensure that each indicator adequately represents the latent variable. Tests conducted on the outer model include convergent validity, average variance extracted (AVE), composite reliability, and Cronbach's alpha (Hair et al., 2017). Convergent validity is tested through factor loadings, with values >0.7 considered adequate. AVE, which measures the proportion of variance explained by the indicators in each construct, should be >0.5. Composite reliability with a value >0.7 indicates high internal consistency, while Cronbach's alpha >0.6 indicates adequate construct reliability. The outer model ensures that the measurement indicators are valid and reliable before structural analysis is performed.

The inner model evaluates the structural relationship between latent variables by looking at the R^2 value of the dependent variable, which shows how much variance is explained by the independent latent variables. Changes in the R^2 value are used to assess whether the independent variables have a substantive effect on the dependent variable. According to Colton (1974), the strength of the relationship between two variables is divided into four categories, as shown in Table 1. This evaluation helps to understand the magnitude and significance of the relationship being tested.

Table 1. The Power of Relationships According to Colton

Correlation Coefficient (r)	Relationship Strength
0.00 – 0.25	Weak
0.26 – 0.50	Moderate
0.51 – 0.75	Strong
0.76 – 1.00	Very Strong

All ethical considerations were met during questionnaire distribution and data collection, including voluntary participation and respondent confidentiality. Using SEM, this study provides a comprehensive understanding of the factors that influence food availability in North Sumatra (Hair et al., 2019; Henseler et al., 2015).

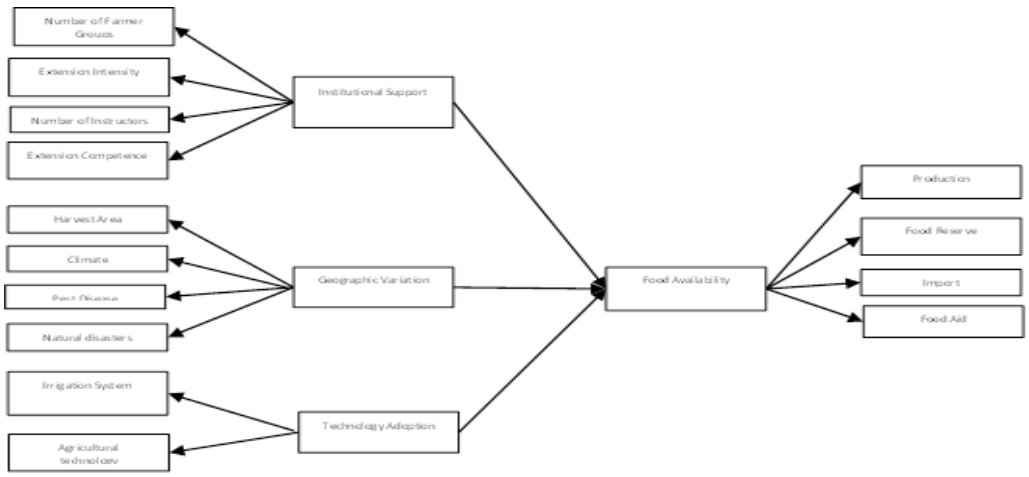

Figure 1.Research framework

4. Results and Discussion

Results

4.1 Outer Model

The outer model test was conducted to ensure the validity and reliability of the construct through convergent validity testing (outer loading and AVE) and reliability testing (Cronbach's alpha and Composite Reliability). The validity test results are shown in Table 2 below:

Table 2. Validity test results

Variable		Outer loading	AVE	Description
Institutional support	X1.1	0.788	0.672	Valid
	X1.2	0.988		Valid
	X1.3	0855		Valid
	X1.4	0.681		Valid
Geographic variation	X2.1	0.660	0.771	Valid
	X2.2	0.806		Valid
	X2.3	0.803		Valid
	X2.4	0.968		Valid
Technology adoption	X3.1	0.871	0.648	Valid
	X3.2	0.999		Valid
Food availability	Y.1	0.757	0.763	Valid
	Y.2	0.747		Valid
	Y.3	0.815		Valid
	Y.4	0.994		Valid

The All indicators meet the convergent validity criteria because the outer loading values are above the minimum threshold of 0.60 and the AVE of each construct exceeds 0.50. This indicates that the indicators have successfully represented the latent constructs adequately. The reliability test results are shown in Table 3 below:

Table 3. Reliability test results

Variable	Cronbach alpha	Composite reliability	Description
Institutional support	0.878	0.911	Reliable
Geographic variation	0.926	0.941	Reliable
Technology adoption	0.953	0.944	Reliable
Food availability	0.922	0.948	Reliable

The convergent testing results were visualized through the PLS-SEM model after the unqualified indicators were removed (Figure 2). All indicators had a loading factor >0.6, so the analysis could proceed to the inner model.

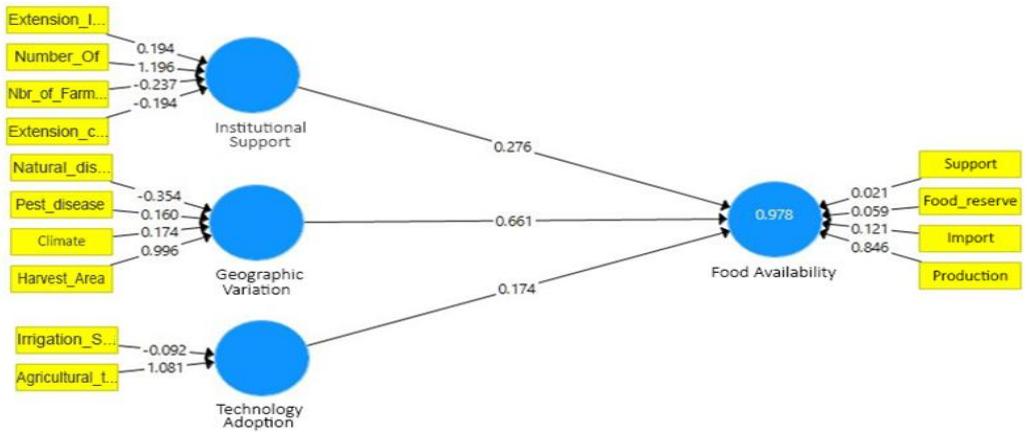

Figure 2. Convergent validity test after modification

4.2 Inner Model

The structural model (inner model) was evaluated by looking at the R-Square value as a measure of predictive power and the path coefficient value to test the influence between variables. The R-Square results are presented in Table 4 below:

Table 4. R-square table

	R-Square	R-Square Adjusted
Food Availability	0.978	0.973

This value indicates that 97.8% of the variance in Food Availability can be explained by Institutional Support, Geographic Variation, and Technology Adoption. This indicates a very strong structural model. The results of the path coefficient testing are presented in Table 5.

Table 5. Inner model analysis results

	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T-statistics (|O/STDEV|)	*P*-values
Institutional support on food availability	0.476	0.316	0.316	2.874	0.038
Geographic variation on food availability	0.661	0.570	0.385	6.716	0.009
Technology adoption on food availability	0.174	0.155	0.238	0.729	0.467

The results show that Institutional Support and Geographic Variation have a significant effect on Food Availability, while Technology Adoption does not show a significant effect.

Discussion

The findings confirm that institutional support is an important factor in increasing food availability. Strong institutional support, such as training, extension services, and production facilitation, is a key mechanism that helps farmers increase productivity. These findings underscore the strategic role of local institutions in strengthening production capacity, in line with the findings of (Abdul-Rahaman & Abdulai, 2018), which show that farmer groups with institutional support tend to have higher productivity. This adds to the empirical evidence that institutional intervention remains a fundamental component in maintaining food stability.

Geographical variations were found to have the most dominant influence on food availability. Physical environmental conditions such as soil quality, topography, rainfall, and natural disaster risk proved to be the main determinants of production success. These results reinforce previous literature (Awazi & Tchamba, 2019; Basir-Cyio et al., 2020) showing that land degradation and climate change pose serious threats to agricultural sustainability. This study fills a

gap by showing that even in relatively homogeneous local contexts, geographic variation still has a significantly greater effect than other factors.

Unlike many studies that emphasize the importance of modern agricultural technology, this study found that the adoption of technology does not have a significant effect on food availability. This shows a gap between the potential of technology and its implementation in the field. Farmers' low capacity to operate technology, lack of supporting infrastructure, or technology that is not suited to local needs may be the causes of this insignificance. These findings contradict (Murray et al., 2018) argument regarding the role of technology in increasing productivity, but at the same time contribute new insights by emphasizing that technology is not always a crucial factor in all contexts.

Theoretically, this study enriches the conceptual model related to food availability by integrating three important dimensions: institutional, geographical environment, and technology. Practically, these results confirm the urgency of strengthening institutions and regional management as policy priorities rather than encouraging massive technology adoption without resource readiness. Governments and related institutions need to focus their interventions on increasing farmer capacity, improving infrastructure, and mitigating environmental risks to ensure food sustainability.

This study has several limitations, including a limited geographical scope and the use of technology variables that do not fully reflect the complexity of modern agricultural technology. Perception-based measurement instruments also have the potential for bias. Future research should expand the geographical coverage, include more detailed technology indicators, and combine objective field data to improve the accuracy of the analysis. In addition, a longitudinal approach could provide a stronger picture of the dynamics of changes in food availability over time

5. Conclusion

The results of the study show that food availability in North Sumatra Province is significantly influenced by institutional support and geographical variations, while the adoption of modern agricultural technology does not have a significant effect. Institutional support through training, extension, and production facilitation has been proven to be a determining factor in increasing farmer productivity, while physical environmental conditions, including soil quality, topography, and rainfall, are the main determinants of production success. These findings confirm that strengthening institutional capacity and regional management should be a policy priority to maintain food stability, while the application of technology must be tailored to farmer capacity and local needs. This study contributes theoretically by expanding the understanding of factors affecting food availability, as well as practical implications for the formulation of intervention strategies by the government and stakeholders in improving food security, although limitations related to geographical coverage and the complexity of technological variables need to be considered in future research.

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